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INCREASE OF THE ABSORPTANCE OF A SHROUD FOR A THERMAL TEST FACILITY AND METHODS OF DETERMINATION

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ABSTRACT

To reduce the large amount of reflected heat radiation by the shroud of the test facility measured during the thermal balance tests on the thermal model of the HELIOS Solar probe at high intensity (16 Solar constants) the testchamber was modified by installation of a shroud with a grooved surface. The paper describes the shroud surface (V-grooves) and the methods used for measuring and calculating the absorptance of the grooved surface.

1. Introduction

According to the mission of the HELIOS Solar probe with a perihelion of 0.25 AU thermal balance tests with simulated solar intensities of 16 S.C. were required. The tests with the thermal model of the HELIOS Solar probe equipped with a thermal canister for simulating intensities of 16 S.C. were carried out in a vacuum chamber with a cold shroud simulating vacuum and cold space environmental conditions respectively. Whereas the influence of the reflected heat radiation from the shroud surface to the thermal model could be neglected at 1 S.C. test conditions there was a considerable simulation error at 16 S.C. test conditions. This simulation error could not be considered with satisfactory accuracy in the mathematical model calculation and therefore it was decided to increase the absorptance of the cold shroud and in this way to reduce the amount of reflected heat energy.

The absorptance was increased by installation of a cold shroud with a grooved surface.(Fig.1 and 2) Published data(1)(2) show that an increase of the absorptance from $\alpha = 0.9$ for the coating to $\alpha = 0.97$ for the coated and V-grooved surface is possible. In this case the apex angle of the V-groove has to be less than 15 degrees. Such a surface was chosen for the modified shroud. (Fig.2)

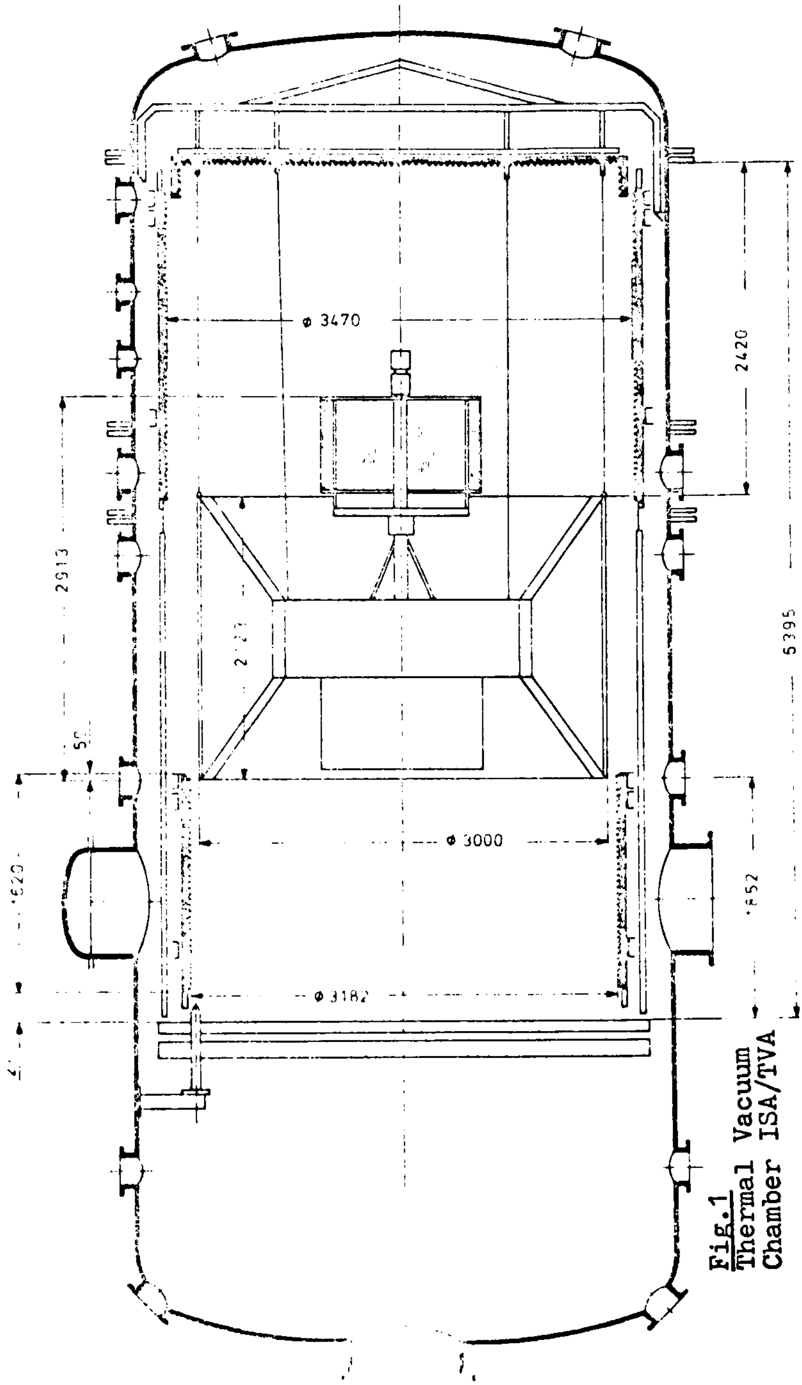
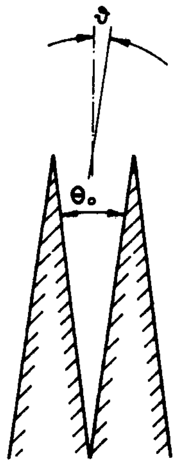
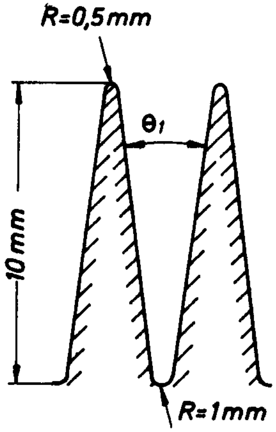


Fig.1
Thermal Vacuum
Chamber ISA/TVA



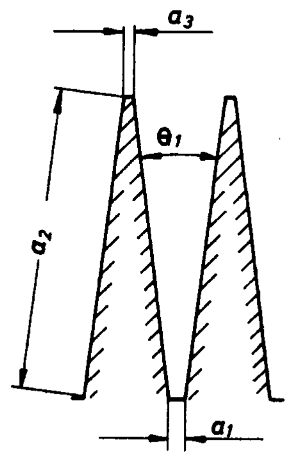
1. Ideal profile

$\Theta_o = 15°$



2. Real profile

$\Theta_1 = 14°$



3. Simplification
of for calculation

$\Theta_1 = 14°$

$a_1 = 0.8$ mm

$a_2 = 10.1$ mm

$a_3 = 1.8$ mm

Shroud surface with V-grooves

Fig. 2

The published data assume V-grooves with sharp edges (ideal grooves) and coating properties of a Lambert radiator. Practically it is not possible to realize these conditions. The V-grooves have rounded edges by reason of manufacturing and the used black paint (Black Velvet Coating 3MCo.) has not a Lambert distribution of radiation.

The aim of the measurements and calculations described in the following is the determination of the absorptance of the V-grooved surface coated with Black Velvet Coating 3M 401 C 10, the increase of the absorptance compared to a flat surface and the difference in absorptance between ideal and real grooved surfaces.

2. Determination of the absorptance of a grooved surface

For the determination of the absorptance three different measuring methods and a calculation procedure were used.

2.1 Measurements

2.1.1 Measurements of the emittance of samples with 90 mm diameter :

The emittance was measured by the PTB (Physikalisch Technische Bundesanstalt) according to a measuring and evaluation procedure developed by Lohrengel(3). This method compares the radiation density of the sample surface with that of a black body of equal temperature under vacuum conditions. The influence on the value of the emittance due to the temperature difference between the black body and the sample was investigated by the above mentioned method and the surface temperature was calculated by considering the radiation interactions of the sample with its environment.
With the above described method the total directional emittance for a flat sample and a grooved sample was measured for sample temperatures of -67° C and +180°C and with these results the total hemispherical emittance was calculated.

In Table 1 and 2 (4), (5) and Fig.3 the results are prepared :

Sample	Sample temperature	wavelength of radiation max.	ε_n	ε_H
Profile vertical	+180°C	6 μm	0.97±0.005	0.94±0.005
Profile horizont.	+180°C*	6 μm	0.97±0.005	0.93±0.005
flat surface	-67°C	14 μm	0.96±0.005	0.90±0.005
flat surface	+180°C	6 μm	0.96±0.005	0.90±0.005

ε_n:emittance in normal direction

Table 1

ε_H:hemispherical emittance

The emittance as a function of emisson direction shows Table 2 and Fig.3 (ϑ is the inclination angle to the normal direction) :

inclination angle ϑ	flat sample $\varepsilon_F(\vartheta)$	Profile vertical $\varepsilon_g(\vartheta)$	Profile horizontal $\varepsilon_g(\vartheta)$
0	0.96	0.97	0.97
30	0.95	0.97	0.97
50	0.94	0.97	0.97
60	0.90	0.96	0.96
70	0.80	0.92	0.88
80	0.58	0.82 (extra pol.)	0.15 (extra pol.)

Table 2

The hemispherical emittance ε_H (Table 1) is calculated from the results $\varepsilon(\vartheta)$ according to the following equation :

$$\varepsilon_H = 2 \int_0^{\pi/2} \varepsilon(\vartheta) \sin\vartheta \cos\vartheta \, d\vartheta \qquad (1)$$

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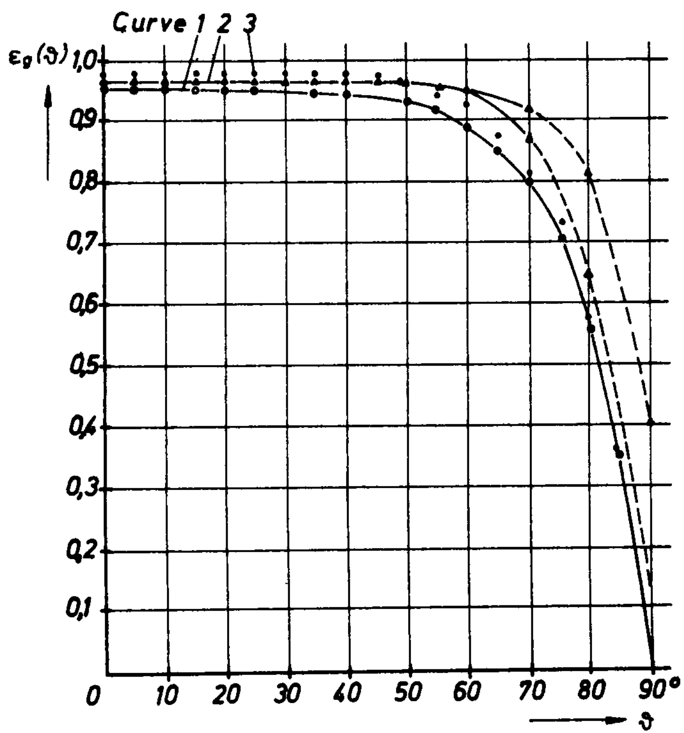

1 Flat sample (s.2.1.1)
2 Grooved sample (s.2.1.1)
3 Grooved sample (s.2.1.3)

Fig. 3
Experimental results for the Emittance $\varepsilon_g(\vartheta)$ as a function of inclination angle ϑ to normal direction

2.1.2 Measurement of the reflectance of heat radiation by a sample of 1m x 1m :

For the measurement of the reflectance of a sample 1m x 1m cooled by liquid nitrogen under vacuum conditions a special measuring equipment by the DFVLR (Institut für Raumsimulation) was developed (6).

The measuring equipment, by which the reflectance in an angle range of $\vartheta = -65^{\circ}$ to $\vartheta = +65^{\circ}$ can be measured, consists of a heated ring and a concentric sensor. The procedure is as follows :

1.) The calibration curve for the determination of the dependence of the temperature of the applied power for the sensor was measured.

2.) The influence of the radiated energy from the ring to the grooved sample and reflected to the sensor was investigated by measuring the sensor temperatur and considering the power according to the calibration curve.

3.) The reflectance is proportinal to the ratio of this power and the radiated energy.

4.) With the aid of the temperature of the sensor and the heater the reflectance was calculated and the temperature of isolating surfaces was considered.

Three test runs gave the following results :

Nr.of Test run	reflectance r according to 1.) - 3.)	reflectance r according to 4.)	Δ r according to 4.)
1	0.031	0.017	±0.008
2	0.030	0.017	±0.008
3	0.028	0.015	±0.007

Table 3

With the results of the table 3 for the reflectance the following values for the absorptance are calculated :

$\alpha = 0.97 \pm 0.01$ (according to 1.) - 3.))

$\alpha = 0.98 \pm 0.01$ (according to 4.))

2.1.3 Measurement of the directional reflectance for samples 20 mm x 20 mm (7):

The directional reflected radiation was measured for wavelengths of 2000 nm and 2500 nm with a Zeiss Spectralphotometer and a rotating sample holder installed in a Ulbricht sphere.
The directional reflectance was determined for inclination angles ϑ to the normal direction between 0^o and 90^o. The measurements were carried out for samples of flat and grooved surfaces. The spectral directional reflectance of the grooved samples was determined by a relative measuring method :
The ratio of the reflected intensity of the grooved and flat surfaces was measured and with the results measured by the above mentioned method 2.1.1 for the same surface the directional reflectance of the grooved surface was calculated. This is an approximation method and was especially used for measuring the possible change of the reflectance of the shroud after the thermal tests with the HELIOS thermal model.

Table 4 and Fig.3 shows the results for the grooved sample. The difference between vertical and horizontal profile was measured < 0.01 :

ϑ	grooved sample $\varepsilon_g(\vartheta)$	
0	0.98	accuracy
30	0.98	$\pm$ 0.02
50	0.97	
60	0.94	
70	0.82	
80	0.59	

Table 4

The hemispherical emittance calculated according to equation (1) is :

$$\varepsilon_{gH} = 0.93 \pm 0.02$$

2.2 Calculation

The calculation of the emittance of the surface with V-grooves is carried out based on a procedure developed by Daws (1). It is assumed that the laquer of the grooved surface behaves in the manner of a Lambert reflector to any incident radiant energy. As characteristic parameters for the radiation properties of

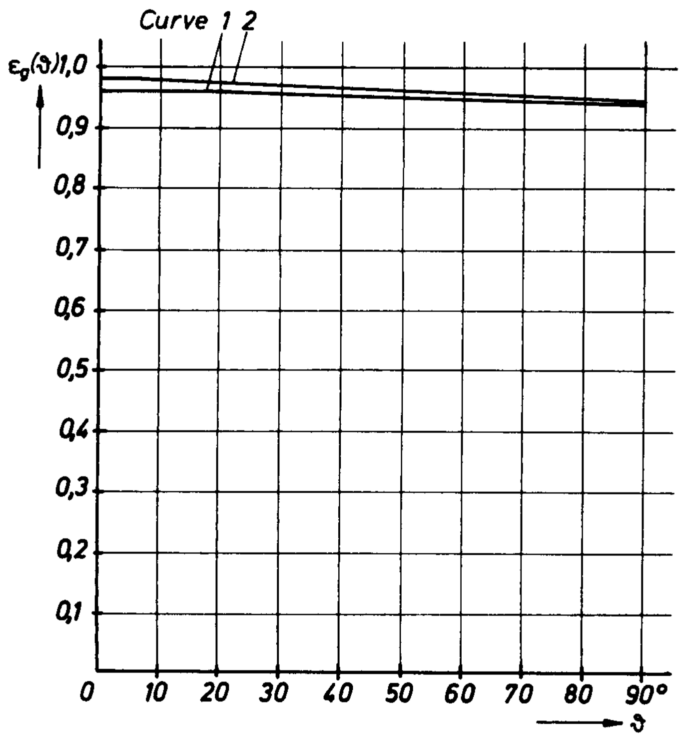

Fig. 4
Theoretical results for the emittance ε_g (ϑ) for a grooved surface described in Fig. 2

the grooved shroud the effective emittance $\varepsilon_g(\vartheta)$ as a function of sighting angle ϑ and the mean effective emittance ε_{gH} over all sighting angles was calculated. The emittance $\varepsilon_g(\vartheta)$ and ε_{gH} is calculated with the assumption of $\varepsilon_F = 0.90$ for the coating (independent of ϑ) for the ideal and real profile (Fig.2) The results are shown in table 5 and Fig.4 :

	ε_{gn}	ε_{gH}
ideal profile $\varepsilon_F = 0.90$	0.99	0.97
real profile $\varepsilon_F = 0.90$	0.97	0.96

Table 5

The values for the hemispherical emittance ε_{gH} in table 5 are in good agreement with results calculated according to the formular of Treuenfels (9) for triangular grooves assuming also the coating is a diffuse reflector :

$$\varepsilon_{gH} = \frac{\varepsilon_F}{\varepsilon_F + f_1(1-\varepsilon_F)} \qquad (2)$$

$$f_1 = 1 - \frac{\pi - \Theta_o}{4} \cos\frac{\Theta_o}{2} \qquad (3)$$

with $\Theta_o = 15^o$, $\varepsilon_F = 0.90$ for the hemispherical emittance follows

$$\varepsilon_{gH} = 0.97.$$

3. Summary of the results and conclusions

In table 6 the results for the emittance of the grooved surface in normal direction ε_{gn} and the hemispherical emittance ε_{gH} are described as a summary :

Measurement/ Calculation	ε_{gn}	ε_{gH}
PTB (S.2.1.1)	0.97 ± 0.005	0.94 ± 0.005
DFVLR(S.2.1.2)	0.98 ± 0.01 0.97 ± 0.01	for angle range -65^o to $+65^o$
IABG(Measurement S.2.1.3)	0.98 ± 0.02	0.93 ± 0.02
IABG(calculation S.2.2)		
real profile $\varepsilon_F = 0.90$	0.97	0.96
ideal profile $\varepsilon_F = 0.90$	0.99	0.97

Table 6

Considering all the described measuring and calculating procedures, their assumptions and accuracies the following values can be stated.

Emittance of a grooved surface (apex angle $\theta_0 = 15^o$) coated with Black Velvet 3 M 401 C 10 :
in normal direction $\varepsilon_{gn} = 0.97$

hemispherical $\varepsilon_{gH} = 0.94$

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